

FIRST COLLECTIVE EFFECTS MEASUREMENTS IN NSLS-II WITH ID'S

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Abstract

As another important milestone towards the final goal to store an average current of 500mA, the average current of 200mA, distributed within ~1000 bunches, was recently achieved in the NSLS-II storage ring after the installation of three Damping Wigglers and four In-Vacuum Undulators. First measurements of the collective effects and instability thresholds, both in single- and multi-bunch mode, are discussed.

INTRODUCTION

The new 3GeV NSLS-II storage ring is in operation with the first six beam-lines designed as a part of the project. The average current of 200mA within ~1000 bunches has been stored as another important milestone in intensity increasing with the final goal of 500mA. For the current lattice configuration with three damping wigglers (3DW's), two Elliptically Polarizing Undulators (EPU's) and four In-Vacuum Undulators (4IVU's) installed and one SC CESR-B 500MHz RF cavity with $V_{RF} = 1.78MV$ used for operation, the estimated RMS bunch duration at low current is $\sigma_s = 6mm$ with energy spread $\sigma_\epsilon = 8.8 \times 10^{-4}$ (Bending Magnets (BM) + 3DW's). The RMS bunch duration, for the bare lattice with DW magnet gaps open, is $\sigma_s = 3.4mm$ with energy spread $\sigma_\epsilon = 5 \times 10^{-4}$. Some key parameters for the collective effects beam studies are given in Table 1.

Table 1: NSLS-II Parameters for Collective Effects Studies

Energy, E_0 (GeV)	3
Revolution period, T_0 (μs)	2.6
Momentum compaction, α	3.7×10^{-4}
Energy loss, U (keV)	287 (BM) 674 (BM+3DW's)
RF voltage, V_{RF} (MV)	1.78
Synchrotron tune, ν_s	6.8×10^{-3}
Damping time, τ_x, τ_s (ms)	54, 27 (w/o DW's) 23, 11.5 (w 3DW's)
Energy spread, σ_ϵ	5×10^{-4} 8.8×10^{-4} (BM+3DW's)
Bunch duration, σ_s (mm)	3.4 (w/o DW's) 6 (w 3DW's) Ignoring bunch lengthen.

SINGLE BUNCH

The stabilizing effect of positive chromaticity on the single bunch threshold current has been studied for a lattice with 3DW's and 4IVU's magnet gap closed (beamline operations). The single bunch current is limited due to the vertical Transverse Mode Coupling Instability

(TMCI). The measured bunch current threshold is $I_{th} = 0.95mA$ at zero chromaticity (Fig. 1a), $I_{th} = 3.2mA$ at chromaticity $\xi_{x/y} = +5/+5$ (Fig. 2a) and $I_{th} = 6mA$ at chromaticity $\xi_{x/y} = +7/+7$. There is no significant effect on increasing the accumulated Single Bunch (SB) current up to chromaticity $\xi_{x/y} = +5/+5$. The horizontal tune shifts as a function of SB current (Figs. 1b, 2b) indicates a stronger effect of the broad-band quadrupole impedance due to installed 4IVUs, to be compared with the results for a bare lattice (w/o ID's) presented in [1], where the horizontal tune shifts were independent of the SB current.

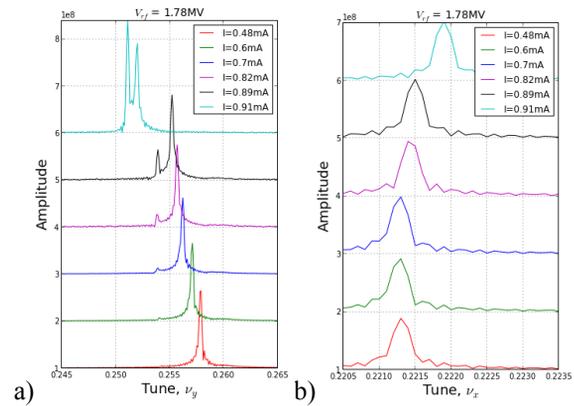


Figure 1: Chromaticity $\xi_{x/y} = 0/0$. All ID's gap closed.

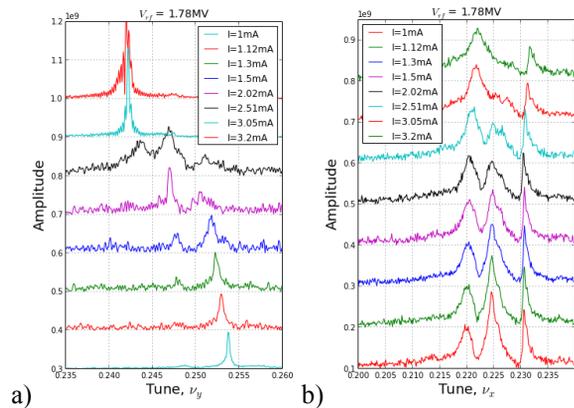


Figure 2: $\xi_{x/y} = +5/+5$. All ID's gap closed.

To adjust the linear chromaticity from zero to $+7/+7$, only the settings of the chromatic sextupoles have been changed. The injection efficiency was 50% at chromaticity $+7/+7$ without further lattice optimization. Betatron oscillations have been excited by kicking the bunch in both directions with horizontal and vertical pingers. The measured spectra (Figs. 1,2) from Turn-by-Turn (TbT) data are plotted with arbitrary offsets and

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amplitudes for different currents. The horizontal tune indicates a positive slope at zero chromaticity as well as at high chromaticity. In Fig. 3 synchrotron light monitor images are shown for two different currents, at 1mA when the single-bunch is stable and at 3.2mA when the single-bunch is unstable due to the TMCI at $\xi_{x/y} = +5/+5$.

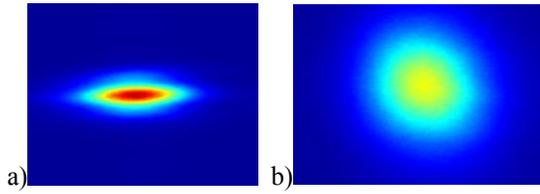


Figure 3: Synchrotron light monitor images for SB currents a) 1mA and b) 3.2mA at $\xi_{x/y} = +5/+5$.

Impedance of 4IVU's

To quantify the effect of the 4IVU's on the total impedance of the storage ring, we compared the vertical and horizontal tunes shifts vs. single bunch current with gaps (DWs and IVUs) open and closed. Fig. 4 shows the results with IVUs gap closed. Fig. 4a shows the vertical tune shift vs. current with DWs gap open (green dots) and with DWs gap closed (blue dots). The higher slope of the tune shift with current for the case with DWs gap open can be explained by the shorter bunch length, 3.4mm, than in the case with DWs gap closed (bunch length 6mm). Fig. 4b shows the horizontal tune shift with current, where the linear fitting of the data gives a positive tune slope due to the quadrupole wakefield effect induced by the 4IVUs. This effect is not present when the 4IVUs gaps are open, as shown in Fig.5 with DW's gap open and close. The contribution of the 4IVUs to the total

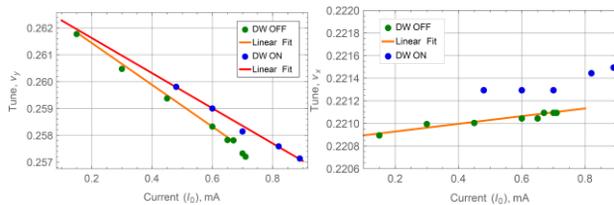


Figure 4: 4IVU's gap closed with 3DW's magnet gap open (DW OFF, bunch length 3.4mm) and closed (DW ON, bunch length 6mm).

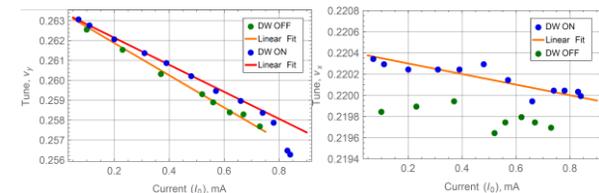
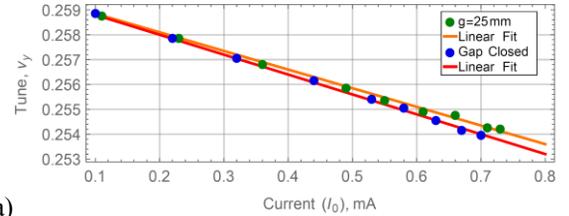


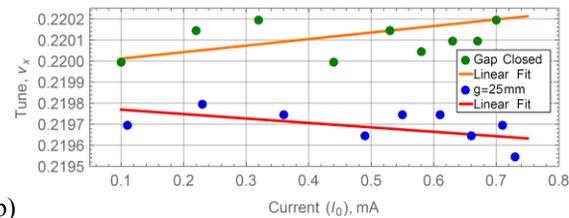
Figure 5: 4 IVU's gap open ($g=40\text{mm}$) for 3DW's magnet gap open (DW OFF, bunch length 3.4mm) and closed (DW ON, bunch length 6mm).

storage ring impedance can be seen from Fig. 6 as well, where the difference in the tune slopes between the case with IVU's gap at intermediate position ($g=25\text{mm}$,

with magnets parallel to full aperture of the vacuum chamber) and IVU's gap closed gives an estimate of the relative contribution to the impedance from the IVU's. The comparison of the vertical tune shifts gives an estimate of 1.5kV/pC/m for the difference in the kick factors. In our analysis of the results the accuracy of the tune measurement from TbT data is of order 10^{-4} .



a)



b)

Figure 6: 4 IVU's gap at intermediate position ($g=25\text{mm}$) and closed. Vertical (a) and horizontal (b) tune shifts as a function of SB current with 3DW's magnet gap open (3.4mm expected bunch length).

Bunch Lengthening Measurements

Streak camera bunch lengthening measurements as a function of SB current are presented in Fig. 7 for various lattice configurations at RF voltage $V_{RF} = 1.78\text{MV}$. The bunch lengthening effect due to potential well distortion is stronger for a bare lattice (blue circles) with 3DW's and 4IVU's magnet gap open up to 1mA SB current. The bunch length at low current is changed as expected with 3DW's magnet gap closed.

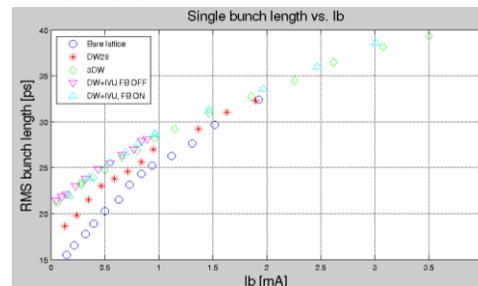


Figure 7: Bunch lengthening measurements.

MULTI-BUNCH

The effect of positive chromaticity, used to stabilize the vertical bunch-to-bunch oscillations with the bunch-by-bunch transverse feedback system switched OFF, has been studied for a lattice with 3DW's and 4IVU's magnet gap open. The chromaticity as a function of average current is shown in Fig. 8. The transverse coupled bunch instability threshold (at zero chromaticity) has been measured at a total average current of $\sim 12\text{mA}$. In our studies, the average current was increased gradually

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within $M=1000$ bunches. The evidence of fast ion instability has been observed at high beam intensity. To suppress the instability developed from bunch-to-bunch, the chromaticity was increased according to the value of the average current. Chromaticity $\xi_{x/y} = +6.5/+7.5$ was required to stabilize the transverse beam motion at an average current of 100mA. Increasing the number of bunch trains and gaps between them helped to reduce the chromaticity value, both horizontal and vertical, as analysed in reference [2].

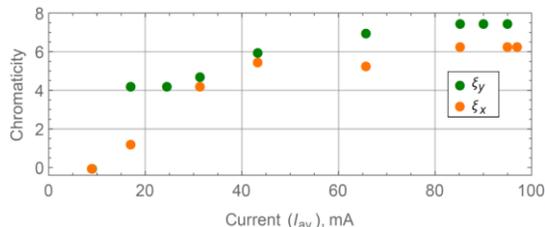


Figure 8: Stabilizing effect of positive chromaticity as a function of average current for one bunch train, $M=1000$.

The betatron tune shifts as a function of average current was studied for different beam-filling patterns as sketched in Fig. 9. As can be seen from Fig. 10 the tune shifts, horizontal (Fig. 10a) and vertical (Fig. 10b), depend linearly on the average current and have opposite slopes. A linear fitting was applied to the measured data and the measured tune slopes are shown in Table 2. The same tune behaviour was obtained for 250 equally spaced bunches and a factor of two difference between the horizontal and vertical tune slopes was observed. Since the results do not depend on the beam-filling pattern we assume the positive slope of the horizontal tune is due to the quadrupole impedance. Our measurements have been done for the lattice with three DW's and four IVU's magnet gap open. The NSLS-II vacuum chamber has octagonal shape with 25mm full vertical aperture and 76mm full horizontal aperture. For a structure mirror-symmetric relative to the $y=0$ plane the transverse transverse-coupling impedance for a driving bunch with transverse coordinate y_d acting on a following bunch with coordinate y_f have the form [3,4]

$$Z_x(x_d, x_f, \omega) \cong x_d Z_{x,D}(\omega) + x_f Z_{x,Q}(\omega) \quad (1)$$

$$Z_y(y_d, y_f, \omega) \cong y_d Z_{y,D}(\omega) - y_f Z_{y,Q}(\omega) \quad (2)$$

where Z_D, Z_Q are the dipole- and quadrupole-impedances. The quadrupole impedance is equal for both directions $Z_{x,Q}(\omega) = -Z_{y,Q}(\omega)$ except the sign. The horizontal dipole impedance is $Z_{x,D}(\omega) < Z_{y,D}(\omega)$ due to geometric dimensions of vacuum elements including the vacuum chamber and In-Vacuum Undulators.

For the horizontal plane the tune shifts can predominantly depend on the quadrupole impedance while the vertical tune shifts have a contribution both from dipole- and quadrupole-impedances. Further analysis is required to interpret the observed tune shifts as a function of average current, as well as a comparison of the results with measurements at other facilities [5,6]. Tune adjustment system is under development.

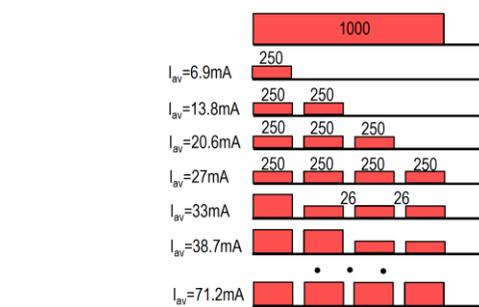
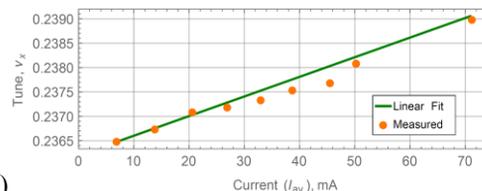
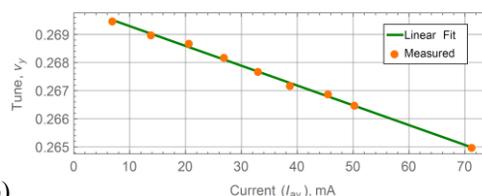


Figure 9: Various beam-filling patterns with different intensity used for tune shifts measurements.



a)



b)

Figure 10: Horizontal (a) and vertical (b) tune shifts as a function of average current for different beam-filling patterns shown in Fig. 11.

Table 2: Measured Tune Shifts as a Function of Current

	Horizontal, A ⁻¹	Vertical, A ⁻¹
Tune Slopes	+0.036	-0.074

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